

MATCHING IN CONCURRENT VARIABLE-INTERVAL AVOIDANCE SCHEDULES

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After pretraining with multiple variable-interval avoidance schedules, two rats were exposed to a series of concurrent variable-interval avoidance schedules. Responses on two levers cancelled delivery of electric shocks arranged according to two independent variable-interval schedules. The ratio of responses and time spent on the two levers approximately matched the ratio of shocks avoided on each. Matching to the number of shocks received was not obtained. Concurrent variable-interval avoidance can therefore be added to the group of positive and negative reinforcement schedules that can be expressed in the quantitative framework of the matching law.

Key words: matching, concurrent avoidance, shock, variable-interval avoidance, lever press, rats

Tests of the matching law (Herrnstein, 1961, 1970) are abundant for positive reinforcement but remain scarce for negative reinforcement (de Villiers, 1977). de Villiers (1974, 1977) has documented the fit of the law to single and multiple variable-interval (VI) schedules using escape and avoidance of aversive stimulation, but only one study (Baum, 1973) has investigated concurrent VI schedules of negative reinforcement. Baum's experiment used pigeons as subjects and escape from shock as the reinforcer, and reported matching of time allocation to the relative frequency of timeouts from shock on the two schedules. Part of the difficulty in doing similar experiments with rats has been that when shock, the most suitable aversive stimulus to use with rats (Azrin and Holz, 1966), is employed in concurrent schedules, many rats will not respond on both response alternatives (Sidman, 1966). This could be due to the rats' freezing on the bars in response to the shock, or to their failing to discriminate the two schedules. The latter possibility can occur when an animal responding on one response alternative receives shocks

scheduled for that or the other response alternative.

The generalized matching law for concurrent schedules (Baum, 1974) states that

$$\frac{B_1}{B_2} = k \left(\frac{R_1}{R_2} \right)^a, \quad (1)$$

where B_1 and B_2 are measures of two behaviors, and R_1 and R_2 represent the reinforcements for those behaviors. The parameter k , when it is not equal to 1.0, expresses a systematic bias toward one or the other alternative; the parameter a is less than 1.0 if undermatching is present, and greater than 1.0 if there is overmatching. In logarithmic form the equation becomes:

$$\log(B_1/B_2) = a \log(R_1/R_2) + \log k, \quad (2)$$

a linear function with slope equal to a and intercept equal to $\log k$. In this form, bias and under- or overmatching can be readily assessed.

The present experiment investigated the fit of the matching law to rats' behavior on concurrent VI shock-avoidance schedules. Rats were pretrained to respond on both levers with a series of multiple VI schedules.

METHOD

Subjects

Three naive, male, Lashley rats served; one was dropped from the experiment during the

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training period. The rats were approximately eight months old at the start of the experiment, and had free access to food and water in their home cages.

Apparatus

A standard rat operant chamber 23 by 19.3 by 20.5 cm was used. Two retractable levers projected into one end of the box 9.5 cm above the floor, 9.9 cm apart, and 2.0 cm from the sides of the box. A minimum force of 0.23 N was necessary to operate each lever. The floor of the box consisted of steel rods 0.2 cm in diameter, spaced 1.2 cm apart. Two white houselights provided illumination. Scheduling was by a system of relays and a PDP-8 computer.

Procedure

Sessions were 1.5 hr long, with data recorded separately for the last 60 min. The white houselights came on when the session started and went off when it ended. Shock intensity was set at 1.5 mA for acquisition training and was changed to 2 mA just before training was finished. Shock duration was 0.30 sec. There was a feedback click for every lever-press response. Sessions were conducted five to six days a week.

Training started with all three rats on a VI 15-sec schedule of avoidance. All variable-interval schedules were constructed according to the progression of Fleshler and Hoffman (1962). Shocks were arranged according to the intervals of the VI. A lever-press response in an intershock interval cancelled the presentation of the next scheduled shock. Further responses in that interval had no effect. Thus, if no responses were made, all shocks arranged by the VI would be received, and if responses were made in each intershock interval, all shocks would be avoided (see de Villiers, 1974, for the advantages of this particular type of avoidance schedule). After stable acquisition of lever-press responding, the schedule was changed to a multiple with 15-min components and VI 30-sec avoidance in each component. Alternate levers were retracted for each component. The length of the components of the multiple schedules was gradually decreased from 15-min to 6-min, 2-min, and finally 30-sec components. Changes were made when behavior appeared stable. R8's response rate became very low when the components were

changed to 30-sec so that it responded only occasionally immediately following a shock. This meant that the animal received a great deal of electric shock. Returning R8 to 2-min and 6-min components and increasing the shock intensity did not alleviate the problem, so it was dropped from the study.

At the end of the training period, which took about 2.5 months, R7 and R9 were begun on a series of concurrent VI avoidance schedules. Both levers were in the box, and responses on a lever cancelled only the next shock arranged by the VI schedule for that lever. A 1-sec changeover delay (COD) ensured that no responses cancelled shocks unless at least 1 sec had elapsed since the last changeover. Table 1 gives the pairs of VIs used and the sequence in which they were presented, along with the number of sessions each was

Table 1

Variable intervals used and the number of sessions each was in effect.

<i>Variable Interval (in seconds)</i>		<i>Number of Sessions</i>
<i>Left</i>	<i>Right</i>	
60	60	16
40	120	21
120	40	27
210	35	29
120	40	29
60	60	28
40	120	37
35	210	26

in effect. The individual VIs used, 35-sec, 40-sec, 60-sec, 120-sec, and 210-sec, had minimum intershock intervals of 2, 2, 3, 5, and 9 sec, respectively. VIs were changed when the behavior of both rats showed no downward or upward trends for five sessions.

RESULTS

Mean response and shock-avoidance rates were calculated over the last five sessions of each condition for R7 and R9. These are given in Table 2, together with the standard deviation of each measure. Since there were substantial warmup effects (de Villiers, 1974; Sidman, 1966), only the last 60 min of data from each session were used. Variability in response rates within and between conditions was somewhat greater than that typically found in concurrent schedules with food reinforcers.

Table 3 shows the means and standard deviations of the logarithms of the ratios (left/

Table 2
Means and Standard Deviations of Response Rates and Shock-Avoidance Rates

<i>Variable Interval (seconds)</i>	<i>Left Responses per Hour</i>	<i>Right Responses per Hour</i>	<i>Total Responses per Hour</i>	<i>Left Shocks Avoided per Hour</i>	<i>Right Shocks Avoided per Hour</i>	<i>Total Shocks Avoided per Hour</i>
R7						
60/60	159.4 (46.5)	10.4 (3.8)	169.8 (44.8)	34.8 (8.5)	6.2 (1.9)	41.0 (8.6)
40/120	159.6 (83.8)	15.4 (11.2)	175.0 (93.2)	42.4 (10.6)	5.8 (3.3)	48.2 (12.8)
120/40	146.0 (28.9)	53.2 (9.3)	199.2 (32.0)	21.2 (1.6)	26.6 (4.5)	47.8 (5.4)
210/35	79.0 (21.2)	165.8 (19.0)	244.8 (23.6)	11.6 (1.5)	59.2 (1.5)	70.8 (2.3)
120/40	65.0 (7.0)	106.0 (6.9)	171.0 (8.5)	15.0 (3.0)	47.2 (3.3)	62.2 (5.3)
60/60	76.6 (23.4)	82.4 (33.7)	159.0 (56.8)	24.6 (4.0)	26.8 (7.1)	51.4 (10.2)
40/120	42.0 (20.9)	17.2 (10.1)	59.2 (30.2)	16.4 (6.7)	7.8 (4.1)	24.2 (10.7)
35/210	174.4 (37.3)	20.2 (15.2)	194.6 (50.2)	44.4 (2.1)	5.4 (1.7)	49.8 (3.6)
R9						
60/60	101.2 (24.1)	145.8 (30.3)	247.0 (50.8)	35.8 (2.6)	38.6 (2.4)	74.4 (4.5)
40/120	43.8 (18.8)	80.6 (26.7)	124.4 (42.5)	28.2 (8.2)	21.2 (3.7)	49.4 (10.8)
120/40	51.6 (11.2)	200.6 (21.0)	252.2 (25.3)	17.6 (3.4)	60.8 (2.9)	78.4 (5.0)
210/35	38.4 (7.0)	259.8 (33.9)	298.2 (29.5)	11.0 (1.4)	68.2 (1.9)	79.2 (1.9)
120/40	53.0 (16.1)	335.0 (22.0)	388.0 (32.6)	18.8 (3.4)	68.8 (2.9)	87.6 (4.5)
60/60	66.4 (17.6)	141.6 (28.5)	208.0 (42.0)	29.0 (4.0)	39.8 (1.0)	68.8 (4.3)
40/120	77.0 (9.3)	52.2 (22.7)	129.2 (30.9)	36.8 (5.6)	14.8 (3.2)	51.6 (7.3)
35/210	66.8 (19.5)	74.4 (39.1)	141.2 (54.5)	30.8 (5.3)	12.4 (1.7)	43.2 (6.2)

NOTE: Numbers in parentheses are standard deviations.

right) calculated for the last five days of each condition for the following variables: responses, cumulated interchangeover time, avoided shocks, and received shocks. The best fit of Equation 2 was determined by the method of least squares for all four combinations of two possible reinforcement variables, received and avoided shocks, and the two dependent variables, lever-press responses, and cumulated interchangeover time on one or the other lever. This was done for R7 and R9 separately. The slopes and intercepts of the functions are shown in Figure 1, which also shows the per-

centage of the variance accounted for by each line. The best fitting lines, as well as the ideal matching lines, with slope of 1.0 and intercept of zero, are indicated in each panel.

DISCUSSION

It is clear from Figure 1 that, despite the variability in the data, the fit of Equation 2 is very good when the number of avoided shocks is used as reinforcement. The lowest proportion of the variance explained is 92.0%. The equation accounts for much less of the

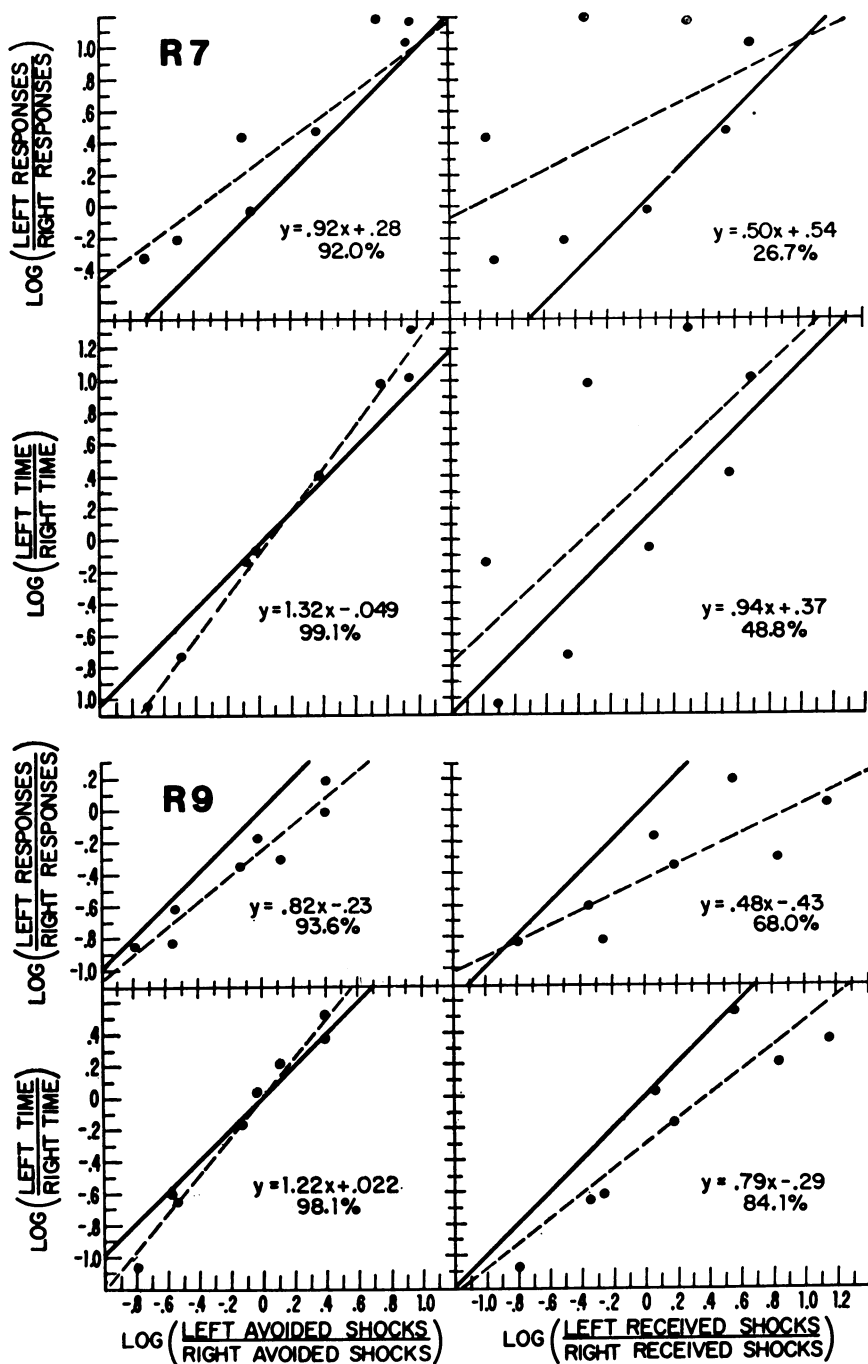


Fig. 1. The ratios of left to right lever-press responses and left to right cumulated interchangeover time as a function of the ratios of left to right avoided shocks and received shocks. Results are shown for the two rats, R7 and R9, and for all eight conditions: eight pairs of VI schedules in which lever-press responses cancelled the next shock arranged by the VI. The solid lines represent ideal matching with a slope of 1.0 and an intercept of zero. The dashed lines are those that best fit the data according to the method of least squares. The equations for these lines and the percentage of the variance they account for are shown in each panel.

Table 3

Means and standard deviations of the logarithms of the ratios (left/right) for the last five days of each condition.

<i>Variable</i>				
<i>Intervals</i>			<i>Avoided</i>	<i>Received</i>
<i>(seconds)</i>	<i>Responses</i>	<i>Time</i>	<i>Shocks</i>	<i>Shocks</i>
R7				
60/60	1.198 (0.294)	0.986 (0.498)	0.758 (0.245)	-0.351 (0.152)
40/120	1.172 (0.428)	1.337 (0.570)	0.962 (0.334)	0.304 (0.111)
120/40	0.439 (0.125)	-0.127 (0.106)	-0.093 (0.081)	-0.977 (0.146)
210/35	-0.334 (0.150)	-1.039 (0.108)	-0.712 (0.064)	-0.921 (0.174)
120/40	-0.214 (0.067)	-0.714 (0.270)	-0.505 (0.083)	-0.483 (0.059)
60/60	-0.016 (0.067)	-0.050 (0.156)	-0.028 (0.104)	0.036 (0.082)
40/120	0.483 (0.347)	0.423 (0.319)	0.369 (0.162)	0.546 (0.060)
35/210	1.027 (0.238)	1.024 (0.389)	0.939 (0.149)	0.693 (0.066)
R9				
60/60	-0.162 (0.068)	0.035 (0.118)	-0.033 (0.027)	0.054 (0.049)
40/120	-0.287 (0.140)	0.220 (0.141)	0.110 (0.128)	0.831 (0.178)
120/40	-0.598 (0.105)	-0.635 (0.127)	-0.546 (0.086)	-0.354 (0.071)
210/35	-0.833 (0.137)	-1.058 (0.237)	-0.796 (0.069)	-0.799 (0.059)
120/40	-0.818 (0.121)	-0.596 (0.149)	-0.570 (0.093)	-0.270 (0.117)
60/60	-0.337 (0.103)	-0.153 (0.134)	-0.142 (0.070)	0.183 (0.060)
40/120	0.202 (0.157)	0.545 (0.217)	0.402 (0.112)	0.562 (0.056)
35/210	0.055 (0.191)	0.372 (0.087)	0.393 (0.080)	1.151 (0.126)

(Numbers in parentheses are standard deviations.)

variance in dependent variable ratios when the number of received shocks is used. This finding is consistent with that of de Villiers (1974), who also obtained a better fit with avoided rather than received shocks, but using single and multiple VI avoidance schedules. However, it should be noted that the present procedure confounded shock-frequency reduction with delay until shock (Hineline, 1977). It cannot be determined from the data which of these exerted control over behavior; it is possible that both were influential.

Table 2 shows that the overall response rates are low, averaging 3.3 responses per minute across both rats and all conditions. The low shock intensity used, 2 mA, may have been at least partly responsible for this. This is

not entirely clear, however, since the low shock intensity may have also helped in not eliciting as many freezing responses, which could interfere with lever pressing.

It could be maintained that the good fit of the matching law, using the number of avoided shocks as the reinforcer, resulted from the low response rates; whenever a response occurred, a shock would be avoided and the matching function thus trivially satisfied. Table 2 shows that in quite a few cases there were fewer responses on a lever than the maximum number of shocks scheduled on that lever for a particular condition. Nevertheless, three aspects of the data argue against this position. First, when each response avoids a shock, responses should match well not only with the number of avoided shocks, but also with the number of received shocks. It might be, in this hypothetical case, that shocks simply elicited responses. But this situation did not occur in the present experiment. Matching of responses and time to received shocks was not as good as to avoided shocks (see Figure 1). Second, a low response rate suggests that scheduled shock frequency could have controlled behavior. If every response removes a shock, the amount of shock-frequency reduction is redundant with the inverse of the maximum scheduled shock rate. Nevertheless, additional analysis, using scheduled shock frequency as the reinforcer, also resulted in a smaller proportion of the variation in responses and time being explained by the matching equation (53.2% and 73.8% for R7, 81.1% and 92.0% for R9, respectively). Third, when the data of Table 2 are examined separately for left and right responses, in only two of 32 cases did either animal make fewer than two responses for each avoided shock.

Figure 1 demonstrates that although responses as a function of avoided shocks fit Equation 2 well, the fit of time as a function of avoided shocks was even better (99.1% of the variance accounted for as opposed to 92.0% for R7, and 98.1% versus 93.6% for R9). Time as a measure of choice, instead of more discrete measures, has been found in other experiments to fit the matching equation well (Baum, 1973; Baum and Rachlin, 1969).

In order for matching to be a good description of the results, not only must the proportion of the variance explained by Equation 2 be high, but the slope in the equation should

be close to 1.0. This would indicate that the animals were neither over- nor underreacting to the distribution of reinforcement between the two response alternatives, compared to what the matching law would predict. Using responses and avoided shocks, the animals both undermatch (slope less than 1.0). On the other hand, they overmatch when time is paired with avoided shocks. However, in all of these cases, the slopes are well within the range of those obtained in concurrent VI schedules of positive reinforcement (de Villiers, 1977).

A COD longer than 1 sec, though usually necessary to obtain matching with rats in concurrent VI food schedules (de Villiers, 1977; Shull and Pliskoff, 1967), was apparently not needed in this experiment. It is possible that this was due to a low changeover rate, which allowed the two concurrent VI schedules to exert separate control over behavior. Unfortunately a programming error prevented the collection of changeovers, but observation of the animals revealed fairly infrequent changeovers between the two levers.

Table 2 also shows marked bias on the part of R7 in the first three conditions. It was not until the fourth pair of VIs that this animal responded more on the right than on the left lever, although two of the three previous conditions delivered more shocks on the right. R9 showed a similar preference for the right lever, but spread more throughout conditions.

The order and repetition of conditions were designed to counterbalance effects of bias, which are due to hysteresis (Stevens, 1957). Equation 2 quantifies systematic bias toward one or the other of the response alternatives (k). This can result from, for example, one lever being harder to push than the other one due to an asymmetry in the levers, or in the animal (Baum, 1974). The intercepts of Figure 1 reveal that, according to this method of analysis, for responses, R7 showed a bias toward the left lever, R9 toward the right. However, for time allocation, bias was virtually nonexistent for both rats.

This experiment shows that maintenance of concurrent VI avoidance can be expressed within the quantitative framework of the matching law, as can concurrent VI positive reinforcement, negative reinforcement in single and multiple VI avoidance schedules (de Villiers, 1974, 1977), and concurrent VI escape schedules (Baum, 1973). The reinforcer for

concurrent VI avoidance is the same one that has been found for single and multiple VI avoidance: the number of avoided shocks. The applicability of the matching law is thus extended to an additional schedule of reinforcement. Although there are schedules which at present cannot be treated within this system (e.g., concurrent variable-interval fixed-interval schedules, see de Villiers, 1977), progress is being made toward a quantitative formulation of choice encompassing both positive and negative reinforcement.

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